USC

CENTER FOR LASER STUDIES
UNIVERSITY OF SOUTHERN CALIFORNIA
UNIVERSITY PARK, DRB-017
LOS ANGELES, CALIFORNIA 90089-1112
USA

CARLTON M. CAVES
ASSOCIATE PROFESSOR
EE/ELECTROPHYSICS
TELEPHONE: (213)743-4382
FAX: (213)749-2193
caves%kumquat@oberon.usc.edu (Internet)
caves%kumquat.usc.edu@interbit (Bitnet)

1988 December 29

Dr. Herschel S. Pilloff
Office of Naval Research
Physics Division (Code 1112LO)
800 North Quincy Street
Arlington, Virginia 22217-5000

Dear Hersch,

This letter reports progress under ONR Contract N00014-88-K-0042 during the period 1987 December 1 to 1988 November 30.

During this period three people were associated with me under this contract at USC. Bonny *Schumaker* of JPL became a part-time Research Scientist at USC on 1988 March 1; her part-time salary (35%) at USC is supported entirely by this contract. Two USC graduate students began Ph.D. research with me during this period. Chang *Zhu* began work with me last spring; he was supported by this contract as a 75% Research Assistant during the summer of 1988 and is presently supported by other funds. Shang *Song* began work with me in September; she is presently supported by other funds. In addition to these people at USC, my two former students at Caltech, Samuel *Braunstein* and David *Crouch*, continued some work supported by ONR. They both finished their Caltech Ph.D.'s in 1988 May. Braunstein is now a postdoc with Pierre Meystre at the Optical Sciences Center of the University of Arizona, and Crouch is a postdoc with Dana Anderson at JILA of the University of Colorado.

Research during this period was concentrated in the following areas:

- *Caves* continued work on the application of squeezed light to laser stabilization. ~~His~~ emphasis shifted from stabilizing intensity to stabilizing frequency (or phase) to a mode of an optical cavity. He investigated the use of squeezed light in the fringe-side scheme for frequency stabilization and in the widely used scheme in which one detects phase-modulated light on reflection from a cavity. This work was reported at the NATO ARW on Squeezed and Non-Classical Light in Cortina, Italy, last January and will appear in the proceedings of the Workshop (publication 2).

• Yariv and *Crouch* considered the effects of internal squeezing on a diode laser. They concluded that amplitude squeezing can reduce the phase fluctuations because of the coupling between amplitude and phase fluctuations in a diode laser. Their work was written up and submitted to *Optics Letters* (publication 3), but has been withdrawn because they did not properly distinguish the statistics inside the cavity from the statistics outside. It is not clear whether the paper will be resurrected.

• *Braunstein* and *Caves* investigated the use of "chained" Bell inequalities to test the objectivity of quantum mechanics. ~~They showed that~~ chaining the standard (and tested) Clauser-Horne-Shimony-Holt Bell inequality can lead to inequalities that display stronger violations by quantum mechanics. They quantified the meaning of "stronger violations" by giving the strength of the violation in units of noise in a model experiment where the dominant noise is statistical. This work was reported at the International Symposium on Spacetime Symmetries at the University of Maryland last May and will appear in the proceedings of the Symposium (publication 4); it was reported again at the Bell's Theorem Workshop at George Mason University in October and will appear in the proceedings of the Workshop (publication 5). A more detailed account has been submitted to *Annals of Physics* (publication 6).

• Peter Drummond of the University of Queensland and *Caves* investigated the channel capacity of a wideband communications channel which has a constraint on its mean power P. They found a capacity given approximately by $\sqrt{P/h}$ bits/sec, both for direct detection of number states and for heterodyne detection of squeezed states, and they suggested that a high T_c superconducting waveguide might meet the physical requirements for attaining the limiting capacity. This work has been written up and submitted to *Nature* (publication 7).

• *Schumaker* continued work on ultrasqueezed light produced by multi-frequency pumping of three-wave and four-wave interactions. For both the three-wave and four-wave cases she has quantified the ultimate noise reduction that can be achieved by use of an optimal detection scheme, and she has shown in both cases that for a fixed pump power one can achieve a greater noise reduction by dividing the power among several pump frequencies, thus producing ultrasqueezed light. This work is presently being written up in two papers, one theoretical and one experimental (co-authored with R. M. Shelby of IBM San Jose).

• *Zhu*, *Song*, and *Caves* resurrected earlier work by *Caves* on the theory of photodetection. Their goal is to develop a genuinely wideband theory that includes spatial attenuation. Their approach is to extend the standard perturbative Glauber theory by including a Langevin equation for the attenuation of the field through the detector. Besides clearing up some conceptual difficulties with the standard theory and clarifying the nature of photons, they hope to be able to investigate such questions as, first, the long-time tails predicted by Pike and Sarkar for a photon-coincidence experiment between the outputs of a parametric amplifier and, second, the optimal quantum states for communication. This work is presently in a very early stage.

During this period *Caves* was an invited speaker at the following conferences: the NATO Advanced Research Workshop on Squeezed and Non-Classical Light, Cortina, Italy, 1988 January 25–29; the Symposium on Precision Measurement with Squeezed Light of the American Physical Society General Meeting, New Orleans, 1988 March 21–25; the International Symposium on Spacetime Symmetries, University of Maryland, 1988 May 24–28; and the IEEE/Leos Annual Meeting, Santa Clara, California, 1988 November 2–4. *Braunstein* attended the International Symposium on Spacetime Symmetries and reported on chained Bell inequalities, and he was an invited speaker at the Bell's Theorem Workshop, George Mason University, 1988 October 21–22.

Sincerely,

Carlton M. Caves

CMC/TEX

Publications submitted

1. D. D. Crouch, "Squeezed states of the electromagnetic field," in A. Yariv, *Quantum Electronics*, Third Edition (Wiley, New York), Sec. 17.9, to be published.
2. C. M. Caves, "Laser stabilization using squeezed light," in *Squeezed and Non-Classical Light*, edited by P. Tombesi and E. R. Pike (Plenum, New York), to be published.
3. A. Yariv and D. D. Crouch, "The spectral consequences of internal squeezing in a laser oscillator," submitted to *Optics Letters* (withdrawn).
4. S. L. Braunstein and C. M. Caves, "Wringing out better Bell inequalities," in *Proceedings of the International Symposium on Spacetime Symmetries*, 1988 May 24–28, University of Maryland, College Park, Maryland, edited by Y. S. Kim and W. W. Zachary, to be published in *Nuclear Physics B*, Proceedings Supplements Section.
5. S. L. Braunstein and C. M. Caves, "Chained Bell inequalities," in *Proceedings of the Bell's Theorem Workshop*, 1988 October 21–22, George Mason University, Fairfax, Virginia, edited by M. Kafatos, to be published.
6. S. L. Braunstein and C. M. Caves, "Wringing out better Bell inequalities," submitted to *Annals of Physics*.
7. P. D. Drummond and C. M. Caves, "Quantum limits on wideband communication rates," submitted to *Nature*.